Economic Based Neural Control Switching of TCR and TSC for Optimal Reactive Power Flow and Harmonic Minimization with Fuzzy-Genetic

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Abstract – **Optimal Reactive Power Flow (ORPF) for improving voltage profile and power loss reduction is very important in power system planning; though its method, constraints, and quality of compensation are very effective. Value of compensator, transformer tap ratio, and generator voltages are assumed as controlling variables. Usually this optimization is accompanied by harmonic production. The most important parameter of reactive power compensators is minimum production of harmonics. Nowadays by considering the improvement of power systems in power quality and the importance of harmonics in power quality, compensators by minimum harmonic distortion should be designed. In this paper, ORPF is executed in two stages. At First stage, a genetic algorithm with a fuzzy fitness model employed to solve this multi objective optimization problem. The entire discrete controlling variable is assumed discretely as their natures in all steps of this stage. Outputs of this stage are values of controlling variable that include compensations values. In Second stage, compensation considering the minimum harmonic production is applied. The issue of harmonic reduction in determining the fire angle of TCR and TSC, that are very important in FACTs, is proposed. Determination of optimum angles for minimizing the total harmonic distortion (THD) is investigated and finally for faster control and decision, Artificial Neural Network (ANN) has been used and satisfactory results have been obtained and to have minimum THD, existence of maximum possible capacitors, if bank of capacitors are employed, for both negative and positive reactive power is calculated.**

Index Terms: **Genetic Algorithm, Fuzzy membership, ANN, ORPF, FACTs, Fire angle, THD.**

I. INTRODUCTION

The reactive power flow [1, 2, 4] in power systems is studied as a key issue for minimizing the power loss and improving voltage profile. Nowadays, Because of simplicity and flexibility of FACTs devices in supplying reactive power, they are so common in power systems. Control of reactive power in these devices could almost be continues. Because of nonlinear relationship between voltage and power loss, reactive power optimization is complicated. So, various methods and algorithms are proposed for solving these optimization problems. One of the best optimization technique which is proposed is the Particle Swarm Optimization technique which has grid tied inverter [25]. Also, in [26], an optimization technique based on mathematical linearizing of nonlinear system is proposed for wind power generation. Moreover, in [27] a control technique based on sum of squares technique which can be used on optimization technique is proposed. Artificial intelligence based methods because of their convenience in use, have widespread usage in solving these problems [28-30].

These algorithms could be classified to numerical and artificial algorithms. Because of vastness of answer sets, using faster searching algorithms is profitable. Genetic algorithm is one of the most ordinary methods of artificial searching. Because of the flexibility in its fitness variation, it is often used in such cases. The aim of optimization project is finding a set of controlling variables that produce favorite objectives and also satisfy experimental constrains.

In first stage of this project, the load curve of this study is divided to several intervals that in each interval the load value is considered as an average value of load curve in that interval. A fuzzy-genetic algorithm is used to determine value of controlling variables in each interval. Fuzzy sets are used to allot fitness values to each chromosome of a generation in genetic algorithm. Real crossover and mutation are used to generate next generation.

For a specific requested reactive power in presence of capacitor bank, there are many opportunities for firing the angles of these devices. In the other stage, compensation considering the minimum harmonic production is applied [11,13,14]. The issue of harmonic reduction in determining the fire angle of TCR and TSC [11,12,14,20,21,22], that are very important in FACTs [19,20,21], is proposed. Determination of optimum angles for minimizing the total harmonic distortion (THD) [15,16,17] is investigated and finally for faster control and making decision, Artificial Neural Network (ANN) has been used and satisfactory results have been obtained and to have minimum THD, existence of maximum possible capacitors, if bank of capacitors are employed, for both negative and positive reactive power is calculated.

II. PROBLEM FORMULATION

In this project fallowing issues are considered:

Power loss reduction: that is fundamental goal in reactive power control.

Voltage profile improvement: to keep buses voltages in an acceptable rang.

Cost function and constraints of this problem are according to formulas (1) and (2)[4]:

$$Min \quad Power\ Loss = \frac{1}{2}\sum_{i}^{N}\sum_{\substack{j=1\\ j\neq i}}^{N} g(i,j)\left[V_i^2 + V_j^2 - 2V_i V_j \cos(\delta_i - \delta_j)\right] \qquad (1)$$

$$\begin{aligned}
& V_{Min}^{l} < V_k^{l} < V_{Max}^{l} && \\
& V_{Min}^{g} < V_k^{g} < V_{Max}^{g} && \text{Continuous Variable Constraint} \\
& Q_{Min}^{g} < Q_k^{g} < Q_{Max}^{g} && \\
& && (2) \\
& Q_{Min}^{c} < Q_k^{c} < Q_{Max}^{c} && \\
& Tap_{Min} < Tap_k < Tap_M && \text{Discrete Variable Constraint} \\
& \Delta P_k = 0 && \\
& \Delta Q_k = 0 && \text{Power Flow Constraint}
\end{aligned}$$

Some of these constraints are the objects that are determined in project and some of them relate to experimental restrictions like generators voltages. Controlling variables are generators voltages (Vg), compensator banks (Q), and tap ratios of transformers (Tapi). Tapi, because of its nature, is discrete variable.

In second stage, for calculated requested reactive power, the fire angles of TCR and TSC are selected such that THD is in its minimum possible value.

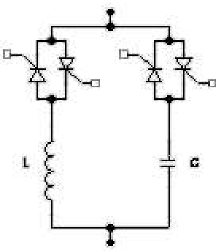
III. SOLUTION ALGORITHM

First, in each interval, an indicative load is substituted instead of variable load and it could be the average load of its period. Then the optimization algorithm is executed as follows [3,4,6,8]:

Optimization algorithm is executed to obtain controlling variables. These variables are chosen such that best voltage profile and minimum power loss are obtained. In this part, generator voltage, Qs and Taps are obtained. A fuzzy-genetic algorithm is used in this part.

In another stage, for all requested reactive power, fire angles of TCR and TSC are calculated for minimizing harmonic production. An ANN is trained suing these couple of angles for making fast decision.

Static reactive power controller is like fig.1 and voltage of these two elements at fire angles α and β are shown in fig. 2 and fig. 3. The goal is determination of α and β for a requested reactive power in case that minimum harmonic is injected to the system.



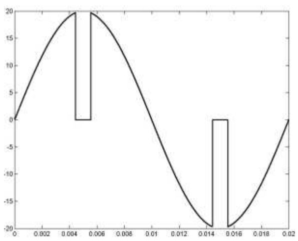
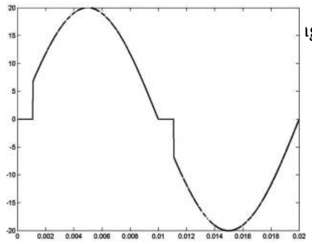


Fig. 1- TSC & TCR combination



ige for β=100

Fig. 3- capacitor voltage for α=20

By coefficients of Fourier series and specifically first coefficient, injected power of capacitor and absorbed power of reactor are calculated. After computing the Fourier coefficients, by considering the relations, currents of reactor and capacitor could be calculated according to (3)[24].

$$\begin{aligned}
& I_c = c\frac{dV_c}{dt} = c\frac{d}{dt}\left(\frac{1}{2}a_{0c} + a_{nc}\cos(n\omega t) + b_{nc}\sin(n\omega t)\right) \\
& \Rightarrow I_c = cn\omega\left(b_{nc}\cos(n\omega t) - a_{nc}\sin(n\omega t)\right) \qquad (3) \\
& I_L = \frac{1}{L}\int V_L dt \quad \cdots \\
& \Rightarrow I_L = \frac{1}{Ln\omega}\left(\frac{1}{2}a_{0L}T + a_n\sin(n\omega t) - b_n\cos(n\omega t)\right)
\end{aligned}$$

Fourier coefficient are rms values of an and bn together. Using these coefficients, THD is calculated. For different values of α and β, injected and absorbed powers are calculated.

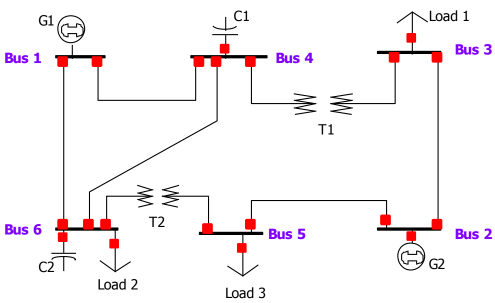
IV. FUZZY-GENETIC ALGORITHM

For using a Genetic Algorithms [1,2,5,9,10], a number of sets of possible answers that consist of real variables, without coding, are randomly chosen and for all sets of a generation, load flow is executed. Power loss and bus voltage that are obtained from load flow, are considered as fuzzy parameters [7] and according to the membership functions of power loss and voltage, membership values are devoted to these variables. The total value of these membership values is assumed as fitness and is used in genetic algorithm execution. Fitness value is obtained using

$$Fitness = \sum_{i=1:Nbus}\mu_{Vbus_i} + \mu_{Poweloss}$$

V. OBTAINED RESULTS

A 6-bus Ward-Hale system is used for testing the proposed algorithm. Fig. 4 shows this system. Table 1 shows the name and values of controlling and dependent variables in system. Table 2 is brought for loading this network. Loads written in table 2 are the loads of 4 intervals said before [4,6].



and this network is used to obtain β and α is obtained from THD minimization in two cases; α=180 for negative requested power and α=0 for positive requested power. For example α and β are shown for specific requested powers of -5MVar in table 5 [24].

Fig. 4- Ward-Hale system

TABLE 1
CONTROLLING VARIABLES AND DEPENDENT VARIABLES

Dependent Variables	Limits		Control Variables	Limits	
	Low	High		Low	High
Qg1(MVar)	-20	100	Vg1(P.U.)	1	1.1
Qg2(MVar)	-20	100	Vg2(P.U.)	1.1	1.15
V3(P.U.)	0.95	1.05	Qc1(MW)	0	15
V4(P.U.)	0.95	1.05	Qc2(MW)	0	30
V5(P.U.)	0.95	1.05	T1(Ratio)	0.98	1.02
V6(P.U.)	0.95	1.05	T2(Ratio)	0.98	1.02

TABLE 2
LOAD VARIABLES MVar

Bus	**P_1(MW)**	**Q1(MVar)**	**P_2(MW)**	**Q2(MVar)**	**P_3(MW)**	**Q3(MVar)**	**P_4(MW)**	**Q4(MVar)**
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	60.5	12.1	82.5	16.5	68.75	13.75	49.5	9.9
4	0	0	0	0	0	0	0	0
5	33	19.8	45	27	37.5	22.5	27	16.2
6	55	11	75	15	62.5	12.5	45	9

Obtained voltages from load flow for considered loads are according to table 3. In this load flow V_g is set in middle of its range.

TABLE 3
VALUE OF VARIABLE AFTER LOAD FLOW

Bus	Load 1			Load 2		
	P(MW)	Q(MVar)	V(p.u)	P(MW)	Q(MVar)	V(p.u)
1	112.07	55.468	1.05	191.9	138.36	1.05
2	50	34.948	1.105	50	74.235	1.105
3	0	0	0.90805	0	0	0.77067
4	0	0	0.9204	0	0	0.78019
5	0	0	0.88092	0	0	0.73041
6	0	0	0.88961	0	0	0.71777
Loss	13.566	47.516		39.402	154.09	
Bus	Load 3			Load 4		
	P(MW)	Q(MVar)	V(p.u)	P(MW)	Q(MVar)	V(p.u)
1	137.64	74.192	1.05	80.595	38.452	1.05
2	50	44.647	1.105	50	24.96	1.105
3	0	0	0.8745	0	0	0.94199
4	0	0	0.88648	0	0	0.95443
5	0	0	0.8428	0	0	0.9209
6	0	0	0.84761	0	0	0.93244
Loss	18.889	70.089		9.0948	28.312	

Optimization for every interval is done independently. Controlling variables and dependent variables are shown in table 4.

For a system with a fix capacitor, using the obtained data that minimize THD from previous stage, a neural network is trained

TABLE 4
VALUE OF CONTROLLING AND DEPENDING VARIABLE AFTER OPTIMIZATION

Variable	**Load 1**		**Load 2**	
	ORPF	**Before ORPF**	**ORPF**	**Before ORPF**
Vg1(P.U.)	1.099	1.05	1	1.05
Vg2(P.U.)	1.135	1.105	1.139	1.105
V3(P.U.)	0.987	0.90805	1.01	0.77067
V4(P.U.)	1.00	0.9204	1.02	0.78019
V5(P.U.)	0.963	0.88092	0.98	0.73041
V6(P.U.)	0.989	0.88961	1	0.71777
T1(Ratio)	1	1	1	1
T2(Ratio)	1	1	1	1
Qc1(MVar)	20	0	20	0
Qc2(Mvar)	5	0	0	0
Loss(MW)	10.482789	13.566	13.111822	39.402
Variable	**Load 3**		**Load 4**	
	ORPF	**Before ORPF**	**ORPF**	**Before ORPF**
Vg1(P.U.)	1.099	1.05	1.097	1.05
Vg2(P.U.)	1.148	1.105	1.149	1.105
V3(P.U.)	0.958	0.8745	1.02	0.94199
V4(P.U.)	0.972	0.88648	1.04	0.95443
V5(P.U.)	0.956	0.8428	1.03	0.9209
V6(P.U.)	0.962	0.84761	1.04	0.93244
T1(Ratio)	.98	1	.98	1
T2(Ratio)	1	1	1	1
Qc1(MVar)	5	0	15	0
Qc2(Mvar)	5	0	5	0
Loss(MW)	13.963364	18.889	7.0064093	9.0948

TABLE 5
α AND β VALUES FOR REQUESTED REACTIVE POWER OF -5MVar

α	**β**	**THD**	**Q**
82.5	91.5	3.5985	-5.0002
90	93.5	3.6289	-5.0007
99.5	96	3.5783	-4.9945
105.5	97.5	3.4961	-5.0042
112.5	99	3.3527	-4.9939
115	99.5	3.2885	-5.0013
117.5	100	3.2179	-4.998
137	102.5	2.4765	-4.9983
144.5	103	2.106	-4.9995
169.5	103.5	0.66205	-4.9912
170	103.5	0.63215	-4.9914
171	103.5	0.56472	-4.9917
171.5	103.5	0.5347	-4.9918
172.5	103.5	0.47455	-4.992
173.5	103.5	0.41428	-4.9921

α	β using analytic method	β using neural network	Q
180	90	90	-10
180	93.5	93.5	-8.5139
180	97	96.991	-7.157
180	101.5	101.52	-5.5839
180	106.5	106.5	-4.1513
180	113	113	-2.6464
180	123	123	-1.171
0	91.5	91.5	0.63004
0	95	95	2.1108
0	99	99	3.5759
0	104	104.01	5.184
0	109.5	109.47	6.5901
0	118	117.99	8.1906
0	136.5	136.8	9.7252

174.5	103.5	0.34639	-4.9922
176	103.5	0.25582	-4.9923
177	103.5	0.18801	-4.9923
177.5	103.5	0.15798	-4.9923
178.5	103.5	0.098541	-4.9923
179.5	103.5	0.043002	-4.9923
180	**103.5**	**0.026626**	**-4.9923**

Fig.5 shows the employed system in this stage.

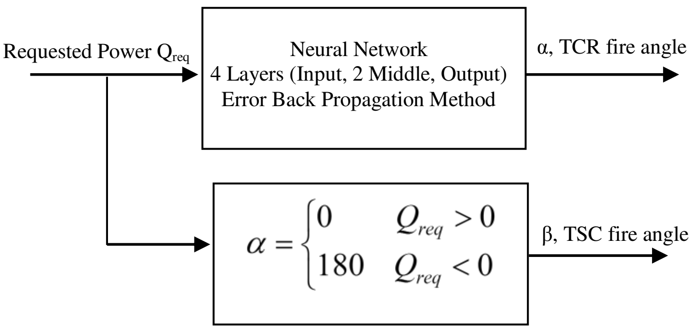


Fig. 5- System employed for determining α and β
For a bank of 1 capacitor

In second system, another neural network is trained for determination of β and number of capacitor banks. From previous discussion, minimum THD takes place in cases that α=0 and α=180. Considering this fact in case of existing a capacitor α=0. Fig. 6 shows the construction of the neural network and its outputs in case of existence of a bank. It should be said that because of the discrete nature of n, it should be rounded. For example, table 5 and 6 show the outputs of neural network for both systems.

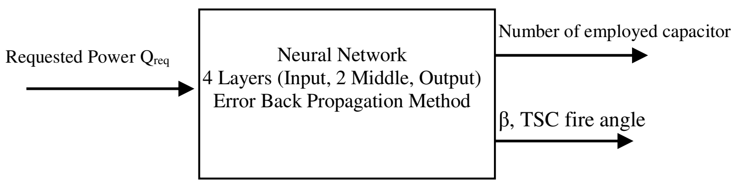


Fig. 6- System employed for determining α and β
For a bank of n capacitor

Table 5
COMPARITION OF α AND β OBTAINED FROM NEURAL NETWORK AND ANALYTIC METHOD

Table 6
β AND N VALUE OBTAINED FROM ANN FOR A REQUESTED REACTIVE POWER AND COMPARING IT WITH ANALYTIC METHOD OUTPUT

N. cap. Analytic Method	N. cap. Neural network	β Analytic meth.	β ANN	Q
0	-0.0221	90	90.038	-10
0	-0.0358	93.5	93.649	-8.505
0	0.2452	97	92.248	-7.1452
2	2.1266	92.5	92.508	-5.5887
3	2.905	92	92.102	-4.1295
4	3.8969	91.5	93.743	-2.6779
6	6.0037	91.5	91.613	0.65545
6	6.0285	95	94.942	2.0955
6	6.0583	99	98.953	3.574
6	5.9073	104	104.02	5.1711
6	5.9477	109.5	109.51	6.6012
6	6.0066	118	118.01	8.1935
6	6.0047	135.5	136.26	9.6894

VI. CONCLUSION

It should be mentioned that discrete amounts in this paper as their natures are considered discrete variables in all stages of investigation.

In case of existing only one capacitor, if requested reactive power is positive, capacitor should be switched and β should be determined for minimizing the THD, and if requested reactive power is negative, capacitor shouldn't be switched on and β should be calculated for minimizing the THD.

And in case of existing a bank, if requested power is positive, maximum capacitors should be switched on and β should be determined to supply requested reactive power ,and when requested power is negative, although reactor is needed, maximum capacitors should be used subject to have a reactor that by adding it to capacitor the requested reactive power is obtained.

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